DYNAMIC TEAR TEST CORRELATION
WITH EXPLOSION BULGE TEST AT
THE SAME TEMPERATURE

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EXECUTIVE SUMMARY

Background

Following the investigation entitled "Toughness Evaluation of Electrogas and Electroslag Weldment"[1] completed in March 1975 by ABS under the welding research project SP 1-3, sponsored by MARAD and ABS, several areas of work were indicated as desirable supplementary follow-on projects. This report provides DT performance for various grades of steel at the same temperatures used for explosion bulge tests. (See Reference (1)). The data is presented as revisions of the text of Reference (1).

Objective

This report is "intended to provide supplementary information to the report "Toughness Evaluation of Electrogas and Electroslag Weldments," March 1975..

Achievement

Dynamic Tear Test (DT) performance of weldments were compared to explosion bulge test performance at the same temperature. The applicable sections in the report "Toughness Evaluation of Electrogas and Electroslag Weldment" were revised to include the additional data and analysis for a further toughness estimate.

Background

As investigation entitled "Toughness Evaluation of Electrogas and Electroslag Weldment"(1) was completed in March 1975 by ABS under the welding research project SP 1-3, sponsored by MARAD and ABS. In this investigation the properties of welds in ordinary and higher strength hull structure steels made with electrogas (EG) and electroslag (ES) high heat input mechanized welding processes were compared with those from the manual metal arc (MMA) and submerged arc welding (SAW) processes with a view toward extending the applicability of the high input processes in shipbuilding. Comparisons were made primarily with respect to toughness as evaluated by explosion bulge, Charpy V-notch, dynamic tear and drop weight tests. The investigation which was exploratory in nature provided several general conclusions relative to the applicability of the high heat input (EG and ES) welding processes to the ordinary and higher strength hull steels. (See Ref. 1). In addition, it indicated several areas of work which were logical follow-on projects to help develop the technology to extend use of the high heat input EG and ES welding processes to shipbuilding. This report covers the results of DT tests for the. various grades of steel which were conducted at the same temperature as the explosion bulge tests. (See Ref. 1).

(1) "Toughness Evaluation of Electrogas and Electroslag Weldments," Project Report by Bethlehem Steel Corporation in cooperation with U. S. Maritime Administration, March 1975.

Objective and Approach

A considerable amount of base material and weldments remained from the previous investigation. This project involves dynamic tear tests on remaining pieces of weldments at the same temperature used for explosion bulge testing to obtain a better estimate of the values of DT tests in predicting explosion bulge results. These DT tests were conducted in the weld and HAZ of MMA, SAW, EG and ES weldments for each grade of material. The applicable sections (Ref. 1) were revised to include the additional data and analysis.

6.2 Evaluation of Weldments - Nondestructive Tests

In general all the weldments met the radiographic and ultrasonic requirements except for small areas of unsoundness connected with starts and stops of the EG and ES weldments which were intentionally discarded during the preparation of test specimens.

6.3 Evaluation of Weldments - Tensile and Bend Tests

All the transverse tensile and bend tests were satisfactory and the all weld metal tensile results were typical for the filler wire.

6.4 Evaluation of Weldments - Small Scale Toughness Tests

Since the primary problem of concern was with toughness degradation in the HAZ, analysis of toughness results was primarily directed toward this area. Toughness degradation for the small scale tests was considered significant based on the following :

CVN - Any value 50% below the minimum expected value for the base material as shown below:

Grade B	20 ft-lbs @ 32F
Grade CS	35 ft-lbs @ -4F
Grade EH36	20 ft-lbs @ -40F

DT - Any value 50% below the determined base material value and below 250 ft-lbs.

DWT - Any increase of NDT of more than 30F above the base material.

6.5 Evaluation of Grade B Weldments

6.5.1 Bulge Tests

The ES weldments exhibited performance equivalent to those of the SAW weldments (20% thickness reduction). The EG weldments exhibited performance similar to those of the MMA. All fractures in the EG weldments initiated in the coarse grain HAZ area with moderate plate deformation

of about 9% thickness reduction. Explosion bulge test results for the EG and ES welds were considered satisfactory since they exhibited similar or better performance as compared to MMA weldments. For reference see Table 20 and Figures 53 through 55 and 64.

6.5.2 Small Scale HAZ Toughness Tests

As indicated in Table 24, CVN tests show the tendency of all the welding processes to produce some degradation in the HAZ. The degradation as measured by each small scale test was as follows:

	BM	MMA	SAW	EG	ES
cvN @ 32F	42	<u>6.3</u>	<u>10</u>	<u>8.3</u>	<u>10</u>
DT @ 120	667	**515**	**797**	**320**	**210**
DT @ 70F	160	240	287	27	244
DT @ 32F	87	147	70	5	26
DWT	20F	- 10F	20F	20F	30F

Values indicating significant degradation according to criteria indicated in 6.4 are underlined. The lowest average CVN values in the HAZ are indicated. The above results indicate that the extent of toughness degradation shown by the CVN and DWT test for the EG and ES welds was not appreciably different than that for the MMA and SAW welds. The DT results at 120F indicated the MMA and SAW weldments were similar to the base material while the toughness of the EG and ES weldments were significantly lower. The DT results at 70F indicated the toughness of ES was equivalent to the MMA and SAW weldments, while the toughness of EG was less than the MMA and SAW weldments. The DT results at 32F indicated brittleness in the base metal, however, the test values for the EG and ES weldments were lower than those of MMA, SAW and the base material. The additional DT tests conducted at 120F indicated a reversal in comparative toughness of the EG and ES weldments from that obtained in the in the tests conducted at 70F, as shown in Figure 27. Figures 28-30 have been modified to indicate the additional tests for Grade CS, CH-36 and A203 respectively.

The specimens from the EG weldments showed somewhat poorer performance than the other processes. Of the three specimens tested two separated and one showed about 50% separation along the weld. All fractures were initiated in the coarse grain HAZ area with moderate degrees of plate deformation ranging from 6 to 11% thickness reduction. As previously noted, the rate of heat in-put for the EG was significantly higher than for the ES; the former used a square butt whereas the latter had a 16 degree included angle. See Table 21 and Figures 56 and 57 and 64.

6.6.2 Small Scale HAZ Toughness Tests

As indicated in Table 25, some evidence of HAZ degradation was shown in at least one of the small scale tests for each welding process. The degradation as measured by each small scale test was as follows:

	BM	MMA	SAW	EG	ES
CVN @ -4F	110	87	68	33	42
DT @ 70F	935	1082	860	160	240
DT @ 20F	920	177	525	170	-
DT @ -4F	1000	125	558	37	22
DJT	-70F	-20F	-40F	-10F	-40F

Values indicating significant degradation according to criteria indicated in 6.4 are underlined. The average CVN values in the HAZ are indicated.

It is noted that the EG weldments which exhibited a somewhat poorer explosion bulge performance as compared to the other processes also exhibited generally lower toughness in the small scale toughness tests. In regard to the CVN test, the results of the EG and ES weldments were significantly less than base material. However, the above values are considered acceptable for Grade CS material.

From the additional tests conducted at 20F the DT test results for the SAW weldments were significantly better than the MMA weldment. However, since both SAW and MMA weldments indicated satisfactory performance in explosion bulge tests the prediction of bulge performance by DT tests alone is not readily apparent.

four ES specimens separated on the first shot along the weld in the coarse grain HAZ area as shown in Figures 65 and 66. All first shot separations exhibited less than 3% reduction in thickness. One of the two MMA and both SAW weldments were exposed to three shots and exhibited approximately 10% reduction with no visible cracks. The remaining MMA weldment fractured on the third shot with extensive involvement of plate material in the fracture. For reference see Table 22 and Figures 58 through 60.

6.7.2 Small Scale HAZ Toughness Tests

The small scale toughness results shown in Table 26 indicated that the EG and ES weldments had a degraded zone in the HAZ, and had significantly inferior toughness as compared to the MMA and SAW. The extent of degradation was as follows:

	BM	MMA	SAW	EG	ES
CVN @ -40F	62	37	41	5.5	7.0
DT @ 70F	865	615	847	70	55
DT @ OF	985	200	-	72	47
DT @ -40F	108	87	105	20	7
DWT	-90F	-80F	-70F	OF	-10F

Values indicating significant degradation according to the criteria indicated in 6.4 are underlined. The lowest average CVN values in the HAZ are indicated.

From the above, it appears that all of the individual small scale tests would have-clearly predicted the explosion bulge results at OF in the EG and ES welds. The additional DT tests conducted at OF do not change the above analysis .

6.8 Evaluation of Grade ASTM A203 Grade A Weldments

6.8.1 Bulge Tests

The speciments from the EG and ES weldments showed poorer performance than those from the MMA and SAW weldments. Each of the two specimens from the EG and ES weldments withstood single shots without evidence of any cracking; but separated along the weld in the coarse grain area of the HAZ after the second shot with approximately 5% reduction in thickness.

MMA weldments withstood three shots with no separation and approximately 10% reduction in thickness. Fractures formed after the third shot exhibited extensive base metal tearing. The SAW weldments withstood three shots with 11% reduction, with no evidence of cracking. For reference see Table 23 and Figures 61 through 64.

6.8.2 Small Scale HAZ Toughness Tests

The small scale toughness results, as shown in Table 27, indicated that the EG and ES weldments had-inferior toughness as compared to the MMA and SAW weldments. However, the lowest HAZ values indicated for the EG and ES welds would normally be accepted for ABS Grade EH36 since the lowest values indicated approximate Grade EH36 base material requirements. Comparative HAZ values were as follows:

			BM	MMA	SAW	EG	ES
CVN	@	-40F	95	50	79	21	16
DT	@	70F	1200	1200	1130	150	122
DT	@	OF	325	542	603	97	45
DT	@	-40F	65	190	330	5	25
DWT			-100F	-120F	-110F	-80F	-40F

Values indicating significant degradation according to the criteria indicated in 6.4 are underlined. The lowest average CVN values in the HAZ are indicated. The above values indicate the lower toughness which had been evidenced in explosion bulge test was also evidenced in the CVN and DT test. The additional DT tests at OF do not change the above analysis.

6.9 Correlation of Small Scale Toughness Results with Explosion Bulge Tests

The degree of consistency of small scale tests with the comparative performance observed in explosion bulge test was considered to be as follows:

Material	CVN	DT	DWT
B	+	0	+
CS	0	0	0
EH36	+	+	+
ASTM A203 Grade A	+	+	-

(+) indicates a positive correlation
(-) indicates a negative correlation
(0) not definitive

The above tabulation is based on the particular temperatures selected for the referenced tests. In the initial work of this investigation the DT tests were conducted at two temperatures only, 70F and the same temperatures at which the CVN tests were carried out for the applicable grade. However, another investigation (4) has indicated good correlation between D DT and explosion bulge tests conducted at the same temperature; therefore the additional DT tests were conducted for the various grades at the same temperature as the explosion bulge tests. The results of these tests did not change the comparative performances of the DT tests as indicated in the above tabulation.

7.0 DISCUSSION

7.1 Service Experience

It should be recognized that using service experience as the evaluating criteria, MMA, SAW, EG and ES welds in Grade B steel and MMA and SAW welds in Grades CS and EH36 steels have proven satisfactory in service. Accordingly, both the explosion bulge and small scale results from such welds are considered to be representative of satisfactory weldment properties. In this regard, it is well to note that Grade B steel is not employed in the most highly stressed areas of large ship hulls.

7.2 Loading Rate

In considering the significance of the test realts it should be recognized that the loading rate and the extent of deformation involved in explosion bulge testing are far greater than those encountered by hull materials under the usual service conditions. Resistance of Grades B, CS, EH36 and ASTM A203 Grade A materials to fracture propagation may be adversly affected by high loading rates. Accordingly brittle performance in the explosion bulge test at a particular test temperature should not be considered to imply brittle performance at the same temperature under

the lower loading rates of service conditions in a merchant ship structure. However, ductile performance in the explosion bulge test would imply ductile performance of a crack free weld at service conditions at the same temperature.

7.3 Test Temperature

The test temperature selected for each material for the explosion bulge tests was the most suitable for comparing performance of the welding processes. The scope of the project did not provide for evaluation at other temperatures. When evaluating weldments for a particular service condition, consideration should be given to design stress or anticipated service stress, permissible flaw size and safety factor in addition to test temperature and loading rate as mentioned in 7.2 above. In this connection it should be noted that the explosion bulge test temperature, OF for Grades EH36 and ASTM A203 Grade A and 20F for Grade CS, is below the normally referenced 32F service temperature for merchant ships.

7.4 CVN and DT Correlation with Explosion Bulge Tests

This program was conducted using the explosion bulge test as the primary basis for establishing comparative toughness performance; small scale toughness tests were intended to provide supplemental information. However, on the basis of the correlations observed, it appears that a reasonably reliable estimate of comparative explosion bulge performance can be made on the basis of the CVN and DT HAZ toughness tests, with due consideration being given to the test temperatures used for each test, especially for weldments which indicate a marked toughness degradation in the HAZ. In this study the toughness degradation of the Grade B and CS EG and ES weldments was less severe than in the Grade EH-36 and ASTM A203 EG and ES weldments and the bulge predictability based on CVN tests was somewhat more consistent.

8.9

Results of CVN and DT toughness tests have shown reasonable correlation with explosion bulge performance, when due consideration is given to selection of test temperature. However, the CVN tests in the HAZ appear to be somewhat more consistent than the DT tests for weldments where the toughness degradation is less severe.

8.10

CVN tests have been shown capable of indicating abrupt changes in toughness in EG and ES welds within distances as small as approximately 2 mn.

8.11

In general for Grades CS, EH36 and ASTM A203 Grade A steels the high heat input, EG and ES welds exhibited greater HAZ toughness degradation than the conventional MMA and SAW welds.

8.12

The performance of ES welds (410,000 joules/in.) using beveled joints was better than EG welds (710,000 joules/in.) using square joints.

8.13

SAW welds made with the tandem triple arc technique generally exhibited superior toughness in small scale and explosion bulge tests as compared to MMA, EG and ES welds. Only one SAW weld exhibited cracking during explosion bulge testing. However, the cracking was restricted to the bulge area and the specimen remained intact as illustrated in Figure 57.

8.14

When high heat input welding processes such as EG or ES are used for special applications in important areas, the retention of adequate HAZ toughness should be verified by small scale tests, such as CVN test.

8.14 continued

However, in view of the results obtained with the Grade CS steel, the extent of small scale toughness testing of EG *or* ES welds in this steel may be minimized or eliminated, if sufficient data is accumulated to verify that the small scale results obtained herein are consistently obtained in production.

9.0 FUTURE WORK

The work reported herein was exploratory in nature and no attempt was made to cover all facets. However, results have indicated several areas of information which should prove helpful to developing the technology to extend use of high heat input processes such as EF and ES welding in shipbuilding. Table 29 indicates the amount of available base material and weldments remaining from this program. From this remaining material the additional tests indicated in 9.1, 9.2, 9.4 and 9.5 are proposed to resolve some unanswered questions which became evident by this investigation.

9.1

Conduct DT tests of the weld and HAZ for each grade of material at the same temperature used for explosion bulge testing to obtain a better estimate of the value of DT tests in predicting explosion bulge test results. These tests can be readily prepared and tested from remaining weldments. This work has been carried out and the results and analysis incorporated into this supplemental report.

9.2

Determine the degree of improvement in explosion bulge properties of EG and ES weldments in Grade EH36 and ASTM A203 Grade A material which can be obtained by use of procedures using lower heat input rates and modified joint designs than those used in the subject investigation. Should improvement be significant, consideration of this approach for application of EG and ES welding of Grade EH36 steel or other higher strength steels in special application areas may be advisable.

9.2 continued

This effort would require making additional test welds in Grade EH36 and ASTM A203 Grade A from remaining available material for preparation of explosion bulge tests.

9.3

Analyze existing literature for guide lines as to the factors which could be used in selecting a candidate hull material equivalent to Grade EH36

TABLE 11 - MECHANICAL PROPERTIES OF BASE MATERIAL[1]

Grade	B	CS	EH36	ASTM A203 Grade A
Thickness (in.)	1	1¼	1¼	1¼
Deoxidation Practice	Semi-Killed	Killed fine grain	Killed fine grain	Killed fine grain
Heat Treatment	As-Rolled	Normalized	Normalized	Normalized
Ultimate Tensile (ksi)	60.2	64.5	73.7	71.0
Yield (ksi)	32.7	43.6	51.3	52.1
Elong. % in 8 in.	34	32	30	30
CVN (ft-lbs)[2]	42 @ 32 F	110 @ -4 F	62 @ -40 F	95 @ -40 F
DT (ft-lbs)[3]	87 @ 32 F	1000 @ -4 F	108 @ -40 F	65 @ -40 F
DWT - (NDT)	20 F	-70 F	-90 F	-100 F

Notes:
(1) Material purchased to 1973 ABS Rules.
(2) Average of at least three tests.
(3) Average of at least two tests.

TABLE - 12 - MECHANICAL PROPERTIES OF WELDMENTS
ON ABS GRADE B MATERIAL

Welding Method	MMA	SAW	EG	ES
Transverse Tensile [1] (psi)	66,400	65,300	63,800	66,500
Guided Side Bends (180°)	OK	OK	OK	OK
All Weld Metal [1] (psi)				
Tensile	73,000	72,500	94,600	72,500
Yield Point	59,400	55,600	74,500	50,600
% Elong. 2 in.	24	29	22	30
%RA	66	69	62	69
CVN Tested @ 32F [2] (ft.-lbs)				
CL Weld	66.3	85.0	32.6	44.7
Fusion Line	74.3	69.0	11.6	10.0
1 mm	87.3	82.0	8.3	37.0
3mm	88.3	53.0	28.0	83.7
5mm	22.6	78.0	53.3	74.7
7mm	6.3	10.0	65.6	16.0
9mm	6.3	15.0	46.3	33.3
Base Metal	42.0	42.0	42.0	42.0
DT tested @ 120F (ft. -lbs.)				
CL Weld	720	990	328 (4)	420
HAZ	515	797	302	210
Base Metal	667	667	667	667
DT tested @ 70F [3] (ft.- lbs.)				
CL Weld	642	1200	102	206
HAZ	240	287	27	244
Base Metal	160	160	160	160
DT Tested @ 32F [3] (ft. - lbs.)				
CL Weld	232	425	28	73
HAZ	147	70	5	26
Base Metal	87	87	87	87
DWT - (NDT)				
CL Weld	-30F	OF	-30F	- 10F
HAZ	- 10F	+20F	+20F	+30F
Base Metal	+20F	+20F	+20F	+20F

Notes:
1. Average of 2 tests
2. Average of 3 tests
3. Average of 2 tests
4. Average of 4 tests (additional tests were conducted because of scatter in the results)

TABLE 13 - MECHANICAL PROPERTIES OF WEIDMENTS
ON ABS CRADE CS MATERIAL

Welding Method	MMA	SAW	EG	ES
Transverse Tensile (1)	70,000	70,800	69,700	70,100
Guided Side Bends (180) (psi)	OK	OK	OK	OK
All Weld Metal (1) (psi)				
Tensile	81,500	96,400	92,600	103,800
Yield Point	71,400	81,400	76,500	81,800
% Elong. 2 in.	26	22	24	24
% RA	76	64	65	62
CVN Tested @ -4F (2) (ft.-lbs)				
CL Weld	46.6	58.0	37.1	46.6
Fusion Line	81.5	90.0	37.0	57.8
lmm	87.1	69.0	33.0	42.3
3mm	94.8	89.0	51.5	73.5
5mm	117.0	74.0	116.0	106.5
71mn	96.5	71.0	125.0	128.8
9mm	96.6	68.0	128.0	81.6
Base Metal	110.0	110.0	110.0	110.0
DT Tested @ 70F (3) (ft. - lbs.)				
CL Weld	105 (4)	1062	817	800
HAZ	1082	860	160	240
Base Metal	935	935	935	935
DT Tested @ 20F (Ft. - lbs.)				
CL Weld	92	397	212	(5)
HAZ	177	525	170	(5)
Base Metal	920	920	920	920
DT Tested @ -4F (3) (ft. - lbs.)				
CL Weld	10 (4)	185	310	437
HAZ	125	558	37	22
Base Metal	1000	1000	1000	1000
DWT - (NDT)				
Weld	- 70F	-70F	- 80F	-90F
HAZ	- 20F	-40F	- 10F	-40F
Base Metal	-70F	-70F	-70F	- 70F

(1) Average of 2 tests.
(2) Average of 6 Tests.
(3) Average of 2 tests.
(4) Average of 4 tests.
(5) No material available.

NOTES :

The first set of DT had much lower values than expected for a E7018 electrode especially in view of the CVN and DWT indicated. DT retests revealed similar values. Reasons for these unusually low DT values could no be esta blished.

TABLE 14 - MECHANICAL PROPERTIES OF WELDMENTS ON ABS GRADE EH 36 MATERIAL

WELDING METHOD	MMA	SAW	EG	ES
Transverse Tensil (1)	80,700	80,300	76,200	81,900
Guided Side Bends (180°)	OK	OK	OK	OK
All Weld Metal (1) (psi)				
Tensile	95,200	100,200	98,700	109,400
Yield Point	84,900	91,800	80,500	77,000
% Elong. 2 in.	23	22	22	22
%RA	64	66	64	64
CVN Tested @ -40F (2) (Ft. - lbs.)				
CL Weld.	42.6	38.0	23.5	27.0
Fusion Line	52.6	41.0	5.5	26.0
lmm	47.8	52.0	12.6	7.0
31mm	51.9	46.0	15.5	15.6
5mm	39.6	51.0	99.8	87.0
7mm	37.0	42.0	96.1	92.0
9mm	59.9	49.0	106.3	100.0
Base Metal	62.0	62.0	62.0	62.0
DT Tested @ 70F (3) (Ft. - lbs.)				
CL Weld	1070	1047	292	312
HAZ	615	847	70	55
Base Metal	865	865	865	865
DT Tested @ OF (3) (Ft. - Lbs.)				
CL Weld.	155	(4)	295	740
HAZ	200		72	47
Base Material	985		985	985
DT Tested @ -40F (3) (Ft. - Lbs.)				
CL Weld	50	55	42	46
HAZ	87	105	20	7
Base Metal	108	108	108	108
DWT - (NDT)				
CL Weld	-60F	-70F	-90F	- 70F
HAZ	- 80F	-70F	OF	-10F
Base Metal	-90F	-90F	-90F	-90F

NOTES :
1. Average of 2 tests.
2. Average of 6 tests.
3. Average of 2 tests.
4. No material available.

TABLE 15 - MECHANICAL PROPERTIES OF WELDMENTS ON ASTM A203 GRADE A MATERIAL

Welding Method	MMA	SAW	EG	ES
Transverse Tensile (1) (psi)	74,000	73,300	72,900	73,500
Guided Side Bends (180°)	OK	OK	OK	OK
All Weld Metal (1) (psi)				
Tensile	96,200	89,400	92,900	106,500
Yield Point	84,400	80,900	76,800	79,800
% Elong. 2 in.	23	24	24	25
%RA	63	62	64	68
CVN Tested @ -40F (2) (ft. -lbs.)				
CL Weld	55.1	53.0	25.6	51.0
Fusion Line	99.2	87.0	21.0	16.0
1MM	50.4	106.0	26.0	19.0
3mm	89.0	104.0	50.8	46.0
5mm	69.1	100.0	88.5	108.0
71mm	87.0	83.0	118.6	157.0
9mm	87.1	79.0	123.5	151.0
Base Metal	95.0	95.0	95.0	95.0
DT Tested @ 70F (3) (ft-lbs)				
CL Weld	1200	1200	545	807
HAZ	1200	1130	150	122
Base Metal	1200	1200	1200	1200
DT Tested @ OF (ft. -lbs.)				
CT. Weld	292	240	205	345
HAZ	542	603	97	45
Base Metal	325	325	325	325
DT Tested @ -40F (3) (ft-lbs.)				
CL Weld	125	336	127	210
HAZ	190	330	5	25
Base Metal	65	65	65	65
DWT- (NDT)				
CL Weld	-120F	- 80F	-110F	-90F
HAZ	-120F	- 110F	- 80F	-40F
Base Metal	- 100F	- 100F	-100F	- 100F

Notes:
1. Average of 2 tests.
2. Average of 6 tests.
3. Average of 2 tests.

TABLE 24 ANALYSIS OF TEST RESULTS ON GRADE B WELDMENTS

PROCESS	SMALL SCALE TOUGHNESS TEST RESULTS			BULGE TESTS
	CVN @ 32 F	DT @ 120, 70, 32 F	DWT Base Material (NDT) 20F	@ 120 F
MMA	Low HAZ values of 6.3 ft-lb@ 7 to 9mm	HAZ similar to Base Material @ 120F 240 ft-lb in HAZ better than base material @ 70F	Similar to base material	3 shots with 10.5% reduct and base material cracks
SAW	Low HAZ values of 10 ft-lbs @ 7 to 9 mm	Similar to MMA	Similar to MMA	3 shots with 19.5% reduction and no cracks.
EG	Low HAZ values of 8.3 ft-lbs @ fusion line	Brittleness @ 70F	Similar to MMA	Inferior to MMA
ES	Low HAZ values of 10 ft-lbs @ fusion lines	Similar to MMA @ 70F Significantly lower than MMA at 120F	Similar to MMA	Similar to SAW with 18.5% reduction and no cracks.
SUMMARY	All weldments had low toughness zone	EG inferior	All weldments similar	EG inferior

TABLE 25 - ANALYSIS OF TEST RESULTS ON GRADE WELDMENTS

PROCESS	SMALL SCALE TOUGHNESS TEST RESULTS			BULGE TESTS
	CVN @-4F	DT @ 70, 20 &-4F	DWT Base Material (NDT)-70F	@20F
MMA	No significant HAZ degradation from base material of 110 ft-lbs	No significant HAZ degradation @ 20F	Rise in NDT temperature to -20F	No cracks after 3 shots with 12.5% reduction
SAW	Similar HAZ to MMA	Similar to MMA @ 70F Some degradation @ 70F	Rise in NDT temperature to -40F	Similar to MMA
EG	Lower HAZ values to 33 ft-lbs @ 1 mm	Low HAZ toughness @ 70F	Highest rise in NDT temperature to -1OF	Inferior to MMA & SAW
ES	Lower HAZ values of 42 ft-lbs @ 1 mm	Toughness @ 70F (no test @ 20F)	Rise in NDT temperature to -40F	Similar to MMA & SAW
SUMMARY	EC and ES somewhat lower values	EG inferior	EG highest NDT	EG inferior

TABLE 26 - ANALYSIS OF TEST RESULTS ON GRADE EH36 WELDMENTS

PROCESS	SMALL SCALE TOUGHNESS TEST RESULTS			BULGE TESTS
	CVN @ -40 F	DT @ 70 OF & -40F	DWT Base Material (NDT) -90F	@ O F
MMA	Somewhat lower HAZ values of 37 ft-lbs @ 7 mm compared to base metal of 62 ft-lbs	Somewhat lower values values @ 70 F of 615 to 865 ft-lbs of base material and significantly lower HAZ at OF	Similar to base material	10% reduction after 3rd shot
SAW	Similar HAZ to MMA	No degradation (No Test @ OF)	Similar to MMA	Similar to MMA with no cracks
EG	Low HAZ values of 5.5 ft-lbs @ fusion line	Brittleness in HAZ @ 70F	Significant rise in NDT temperature to OF	Significantly inferior to MMA
ES	Lower HAZ values of 7.0 ft-lbs @ 1mm	Brittleness in HAZ @ 70F	Significant rise in NDT temperature to -10 F	Significantly inferior to MMA
SUMMARY	EG and ES lower values	EG and ES brittle	EG and ES high NDT	EG and ES inferior

TABLE 27 - ANALYSIS OF TEST RESULTS ON ASTM A203 GRADE A WELDMENTS

PROCESS	SMALL SCALE TOUGHNESS TEST RESULTS			BULGE TESTS
	CVN @ -40 F	@ 70 OF & -40 F	DWT Base Material (NDT)	@ O F
MMA	Somewhat lower HAZ values of 50 ft-lbs @ 1 mm compared to 95 ft-lbs base mat'l.	No degradation @70 F or OF	No significant degradation	Cracks propagating into base material on 3rd shot 10% reduction
SAW	No significant degradation	Similar to MMA	Similar to MMA	Similar to MMA with no cracks
EG	Lower HAZ values of 21 ft-lbs. @ fusion line	Lower HAZ toughness @ 7 0 F	Rise in NDT temperature of HAZ to	Inferior to MMA
ES	Lower HAZ values of 16 ft-lbs @ fusion line	Low HAZ toughness @ 70 F	Highest rise in NDT temperature of HAZ to -40 F	Inferior to MMA
SUMMARY	EG and ES lower values	EG and ES inferior	EG highest NDT	EG and ES inferic

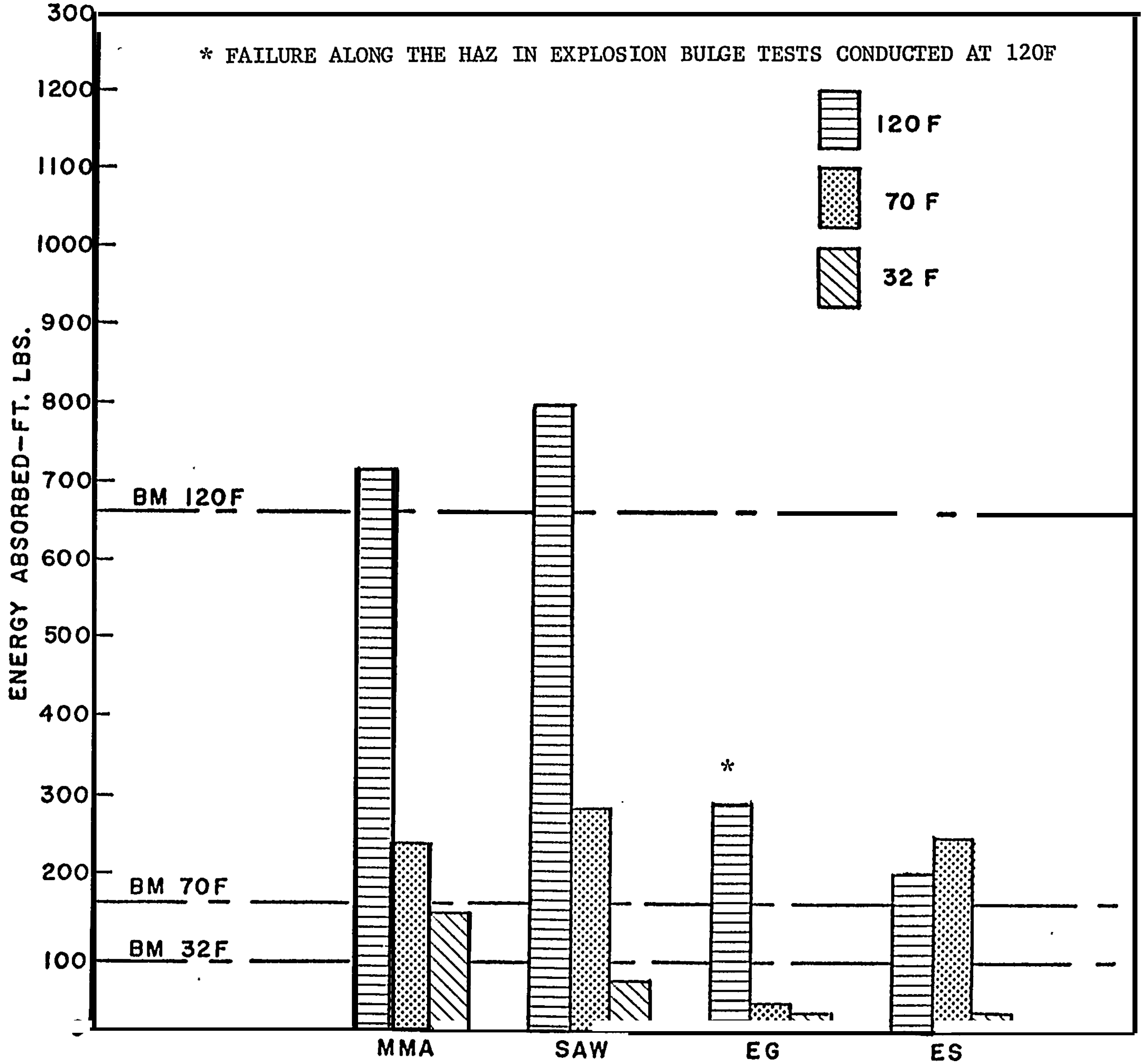

FIGURE 27 DYNAMIC TEAR HAZ TEST RESULTS

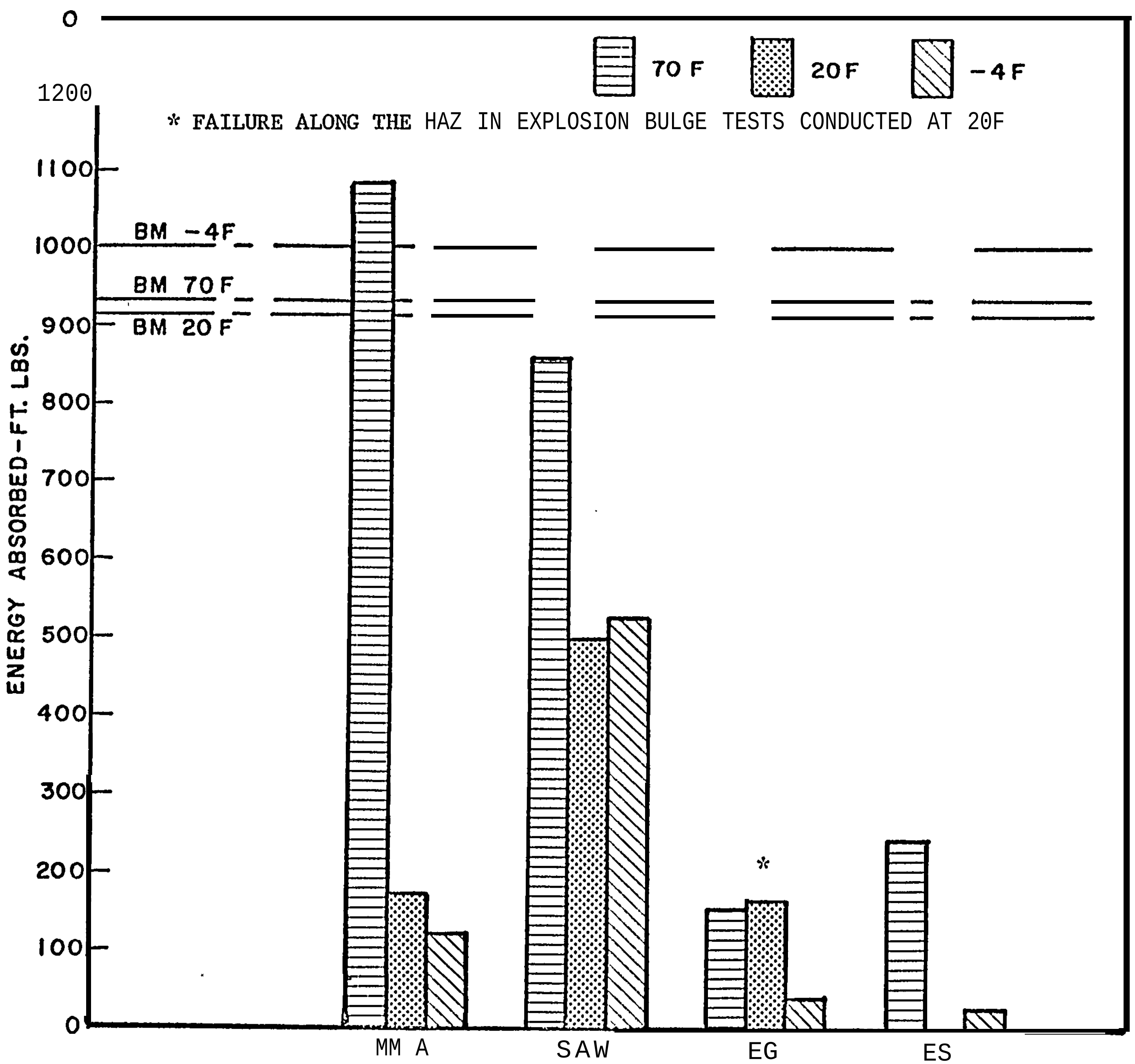

FIGURE 28 DYNAMIC TEAR HAZ TEST RESULTS
GRADE CS MATERIAL

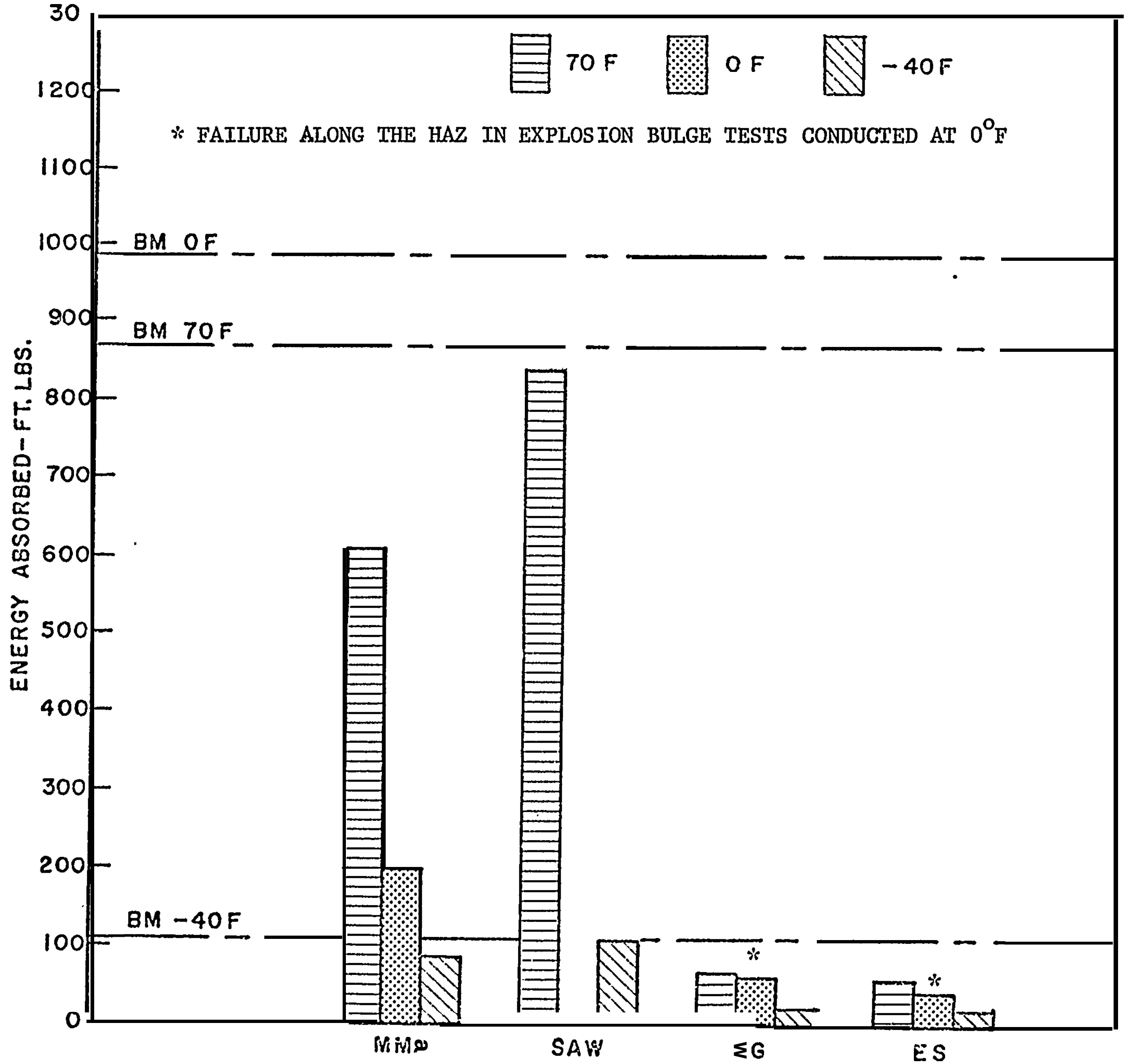

FIGURE 29 - DYNAMIC TEAR HAZ TEST RESULTS
GRADE EH36 MATERIAL

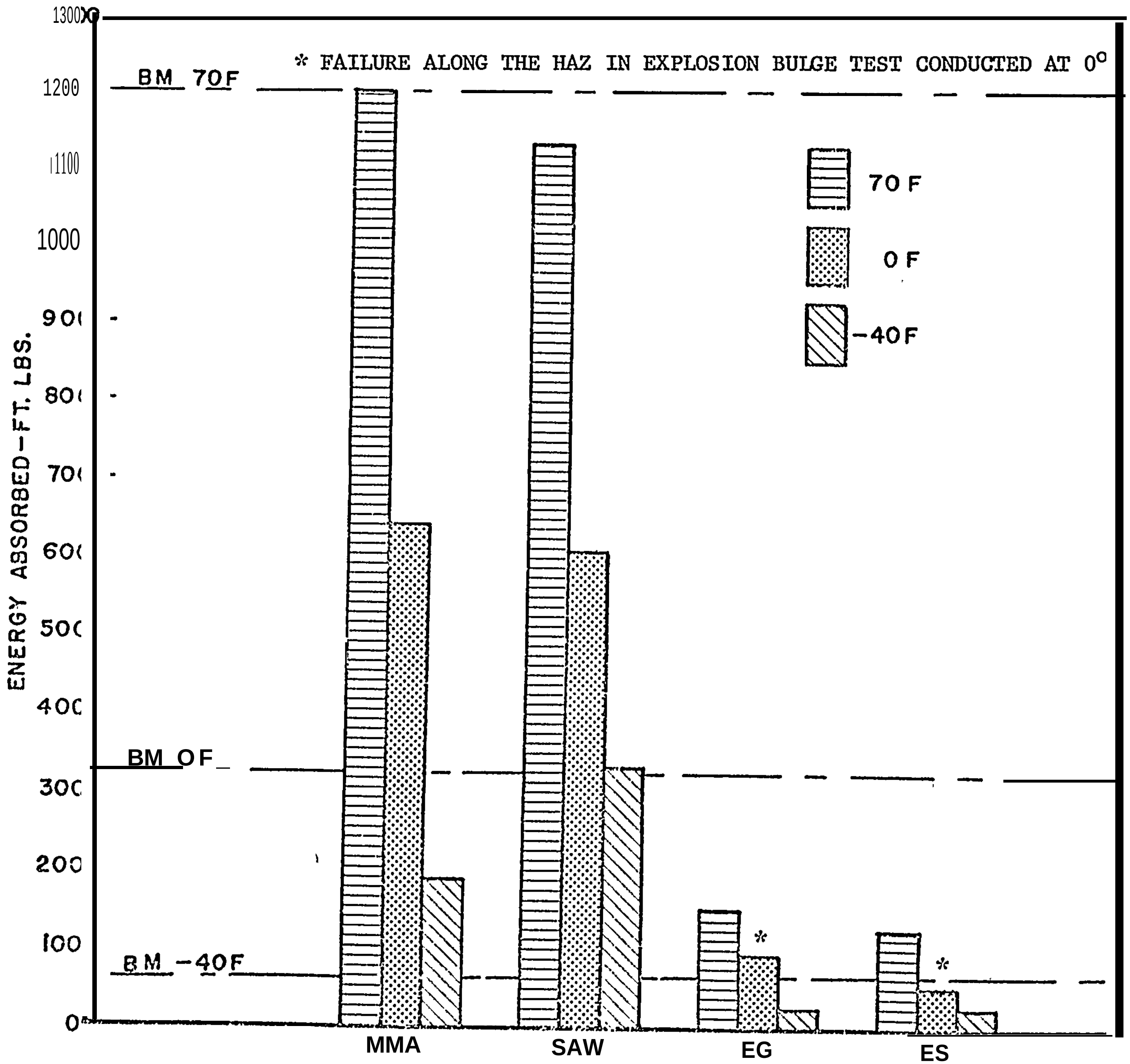

FIGURE 30 - DYNAMIC TEAR HAZ TEST RESULTS
GRADE ASTM A203 MATERIAL